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SAFETY PRACTICES FOLLOWED IN ISRO LAUNCH COMPLEXES – AN OVER VIEW

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ABSTRACT

The spaceport of India, Satish Dhawan Space Centre (SDSC) SHAR of Indian Space Research Organisation (ISRO), is located at Sriharikota, a spindle shaped island on the east coast of southern India.

SDSC SHAR has a unique combination of facilities, such as a solid propellant production plant, a rocket motor static test facility, launch complexes for different types of rockets, telemetry, telecommand, tracking, data acquisition and processing facilities and other support services.

The Solid Propellant Space Booster Plant (SPROB) located at SDSC SHAR produces composite solid propellant for rocket motors of ISRO. The main ingredients of the propellant produced here are ammonium perchlorate (oxidizer), fine aluminium powder (fuel) and hydroxyl terminated polybutadiene (binder).

SDSC SHAR has facilities for testing solid rocket motors, both at ambient conditions and at simulated high altitude conditions. Other test facilities for the environmental testing of rocket motors and their subsystems include Vibration, Shock, Constant Acceleration and Thermal / Humidity.

SDSC SHAR has the necessary infrastructure for launching satellites into low earth orbit, polar orbit and geo-stationary transfer orbit. The launch complexes provide complete support for vehicle assembly, fuelling with both earth storable and cryogenic propellants, checkout and launch operations. Apart from these, it has facilities for launching sounding rockets for studying the Earth's upper atmosphere and for controlled reentry and recovery of ISRO's space capsule reentry missions.

Safety plays a major role at SDSC SHAR right from the mission / facility design phase to post launch operations. This paper presents briefly the infrastructure available at SDSC SHAR of ISRO for launching sounding rockets, satellite launch vehicles, controlled reentry missions and the built in safety systems. The range safety methodology followed as a part of the real time mission monitoring is presented. The built in safety systems provided onboard the launch vehicle are automatic shut off the propulsion system based on real time mission performance and a passivation system incorporated in the orbit insertion stage are highlighted.

1. INTRODUCTION

Satish Dhawan Space Centre SHAR, the Satellite Launching Station of Indian Space Research Organisation (ISRO), popularly known as "Spaceport of India" is situated on an island in the southern part of India. Its geographical location is 13°N and 80°E and ISRO has selected this place for launching satellites due to following advantages:

- Good launch azimuth corridor for various missions (scientific missions using sounding rockets and satellite launch missions to GTO, SSO, LEO)
- Advantage of Earth's rotation for Eastward launchings
- Nearness to the equator
- Largely uninhabited area as safety zone
- Down-range tracking stations

SDSC SHAR, which became operational with the launch of a small sounding rocket on October 9,1971 developed into a world-class spaceport within three decades. It has a unique combination of facilities such

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as a solid propellant plant, a solid rocket motor static testing complex, launch complexes for a variety of missions, telemetry and command stations, tracking radars, real-time data acquisition, data processing facilities for flight safety and mission specialists and other support services.

1.1 Solid Propellant Space Booster Plant (SPROB)

SPROB produces the composite solid propellant, required for 2.8 m diameter rocket motors for PSLV and GSLV. This facility is now further being augmented to make solid motor of 200 tonnes capacity for GSLV Mark III launch vehicles.

The composition of solid propellant manufactured here is ammonium perchlorate as oxidiser, fine aluminium powder as fuel and hydroxyl terminated polybutadiene (HTPB) resin as binder. The rocket motor thus produced undergoes non-destructive testing (NDT) for detecting any flaws like de-bonding, cracks and voids as a part of qualification program.

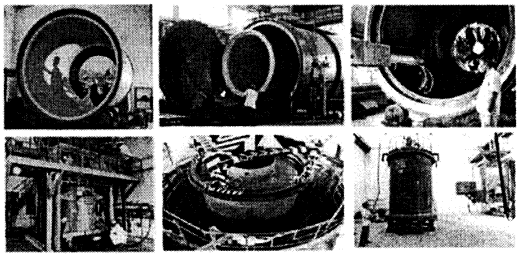

Fig. 1 Processing of a solid propellant booster segment

1.2 Vehicle Assembly and Static Testing Complex (VAST)

Rocket motors and their subsystems are rigorously tested and evaluated on ground before they are declared flight worthy. The performance parameters of a rocket motor like thrust, chamber pressure, skin temperature,

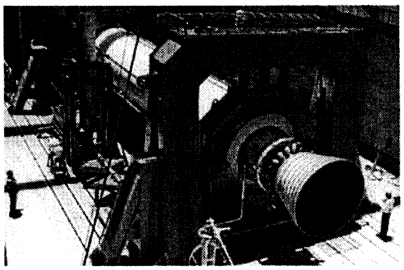

Fig.2 PSLV first stage solid propellant booster on test bed

strain etc., are evaluated by testing on ground under ambient and simulated high altitude conditions. It also has environment simulation facilities (Vibration, Shock, Constant Acceleration, and Thermal / Humidity) for testing solid rocket motors and their subsystems.

1.3 launch complexes

SDSC SHAR has infrastructure for launching sounding rockets and satellite launch vehicles.

2. SAFETY CRITERIA FOR LOCATION OF LAUNCH PAD

Separate launch facilities have been set up for the first generation launch vehicles, namely, SLV-3 and ASLV; first launch pad for the presently operational launch vehicles, namely, PSLV and GSLV and second launch

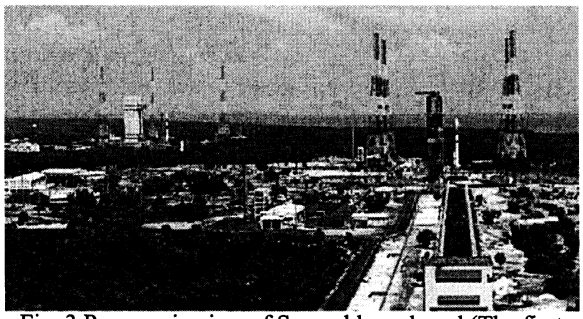

Fig. 3 Panoramic view of Second launch pad (The first launch pad is seen at the background)

pad for PSLV, GSLV and next generation launch vehicles. Each launch pad has its own independent built-in safety systems. This paper highlights the safety systems in second launch pad, which was commissioned in the year 2004.

Following criteria were applied in locating the facilities:

- Net Explosives Quantity (NEQ) versus Distance - as per ISRO standard regulations
- Fire ball effects
- Toxicity effects
- Over pressure and blast wave effects
- Fragmentation effects
- Acoustic levels and effects.

Based on the above safety criteria, an analysis was carried out considering future ISRO launch vehicle variants also. Accordingly facilities are grouped in four categories based on NEQ - Distance from launcher.

Group	Distance (m)	Facility/system
Group –I	Up to 125	Launch vehicle - ground interface room, Cryogenic Propellant cooling System, Overflow-Cum-Pressurisation room.
Group -II	250- 400	Propellant and Gas charging, Electrical power station etc.
Group-III	1000	Assembly and Integration Areas
Group-IV	5000	Mission Control Centre and Satellite Integration / Check-out Facilities

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3.0 BUILT-IN SAFETY SYSTEMS AT SECOND LAUNCH PAD

Based on the hazardous nature of solid propellant, electro explosive devices, earth storable liquid and cryogenic propellants, the safety system are categorized as follows:

3.1. Fire detection and alarm system (FDA)

Addressable fire detection and alarm systems with ionization, photoelectric and heat detectors are installed at all supporting facilities and propellant storages facilities. In fuel storages (UH -25 and LH2), intrinsically safe fire detectors are installed.

Fire alarm system is coupled with air handling unit, to switch off the Air Conditioning (AC) facility and activation of gas based fire suppression system.

3.1.1. UV – IR detectors

In liquid hydrogen storage area, intrinsically safe UV - IR detectors are installed, in addition to addressable smoke detectors.

3.2. Gas monitoring system

Due to the toxicity, flammability and asphyxiating effects from the propellant vapours, gas check system and pollution monitors installed in storages and launch pad. In case of any abnormality due to pollutants, audio and visual alarms are activated.

Gas	Alarm 1	Alarm 2	Alarm 3	Remarks
Oxygen	<19% (v)	>23% (v)		
Hydrogen	10% - 25% LEL	25% - 45% LEL	> 45% LEL	LEL – 40000 ppm
Hydrazine	50 % TLV	100% TLV		TLV – 0.1 ppm
N_2O_4	50 % TLV	100% TLV		TLV – 3 ppm

3.3 Fire fighting system

3.3.1. Water based

Water Based fire suppression system protects launch complex and liquid propellant storage tanks and related facilities against fire hazards. The system is also intended to ensure safety of operating personnel against exposure to toxic and hazardous liquid propellants. Water hose reel, hydrant system, deluge and sprinkler system for liquid propellant storage tanks, remote manoeuvred water monitors, water spray system at umbilical tower are some of the water based fire suppression systems.

3.3.1.1. Sources of water

In case of worst scenarios, like, explosion at launch pad, quantity of water required at source is calculated based on water supply to hydrants and deluges. An Over Head storage Tank (OHT) of capacity 300m^3 and a Ground Level Reservoir (GLR) of capacity 1200 m^3 are the two sources of water. OHT and GLR are interlinked for maximum utilisation of water.

3.3.1.2. Fire hydrant and deluge system

Fire water in the GLR is drawn through six numbers of horizontal split case centrifugal pumps of capacity 410 m^3/hour each and one diesel engine cranked by an air starter driven fire pump (as a standby) with 100m discharge head. It is supplied to the deluge systems in liquid propellant storage and handling areas in launch pad through ground laid piping.

The fire pumps are operated sequentially to avoid sudden dynamic loads in the water main pipe line and at electrical power station.

A jockey pump of 50 m^3 / hour discharge rate at 100m delivery head makes up pressure drop in water mains due to minor leaks in the system.

3.3.1.3. Deluge water systems

The deluge water systems at LH2 and UH25 fuel storage facilities are operated based on following criteria:

LH_2 / UH-25 storage facilities – 25 lpm/m^2
LOX / N_2O_4 storage facilities – 10 lpm/m^2

System is operated either remotely or manually from safety consoles on receipt of alarm signals from fire sensors/pollution monitors/gas check system.

3.3.2. Gas based system

Instrumentation rooms and facilities of high asset value at launch site are provided with gas based automatic total flooding fire suppression system. FM200, zero ozone depletion potential gas based flooding system gets actuated automatically when any two detectors in the room detect the fire. Suppression system can also be actuated manually from safety console at Launch Control Centre located at 5km from the launch pad.

3.3.3. Helium abatement for LH2 system

Helium abatement system is meant for breaking flow of GH2 through the vent lines, which is vented intentionally (purging & venting of yard/UT pipe lines) through the vent stacks, whenever fire is noticed on top of vent stack.

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4. SAFETY DURING ROCKET INTEGRATION

4.1 High pressure system

Flight hardware like pneumatic and hydraulic pressure system components shall be designed to the minimum factor of safety as shown in the following table:

4.2 Electro explosive device

Electro explosive devices are employed for various functions such as separation, destruction, payload fairing jettisoning, etc. Some of the highly hazardous and operationally critical systems are initiated through RMSA (Remote Mounted Safe Arm) units. RMSA outputs are taken to various application points through pyrotechnic circuits consisting of Explosive Transfer Assembly, Explosive Manifolds, Detonation Transfer Junctions and Through Bulk Initiators as the application may be. RMSA contains two numbers of EEDs. Firing of any one of them will ensure initiation of the entire pyro system.

4.2.1. Safety Intercepts

Minimum four numbers of safety intercepts are incorporated in the firing chain of initiation of EED. This includes the intercepts commanded by on-board computers (OBC) during flight.

4.2.2. RF Energy source

For restricting the hazards due to RF energy from all controllable RF sources, the safe practice followed is imposing of RF silence during pyrotechnics wiring operations and arming operations operation.

4.2.3. Control of electrostatic charge

Brass hanging chains and brass handles are installed at the entry of facility to avoid static charge accumulation on the working personnel. One has to pass through the chain and hold the brass handle for a minute to control electrostatic charge. Wriststats, cotton dress, and conducting shoes are mandatory for personnel handling pyrotechnics.

4.3 Protection of launch vehicle against Lightning

	Proof	Design Burst
Lines and fittings dia < 40 mm	1.5	4.0
dia ≥ 40 mm	1.5	2.5
Fluid Return Sections	1.5	3.0
Fluid Return Hose	1.5	5.0
Other pressure Components	1.5	2.5
Components subjected to low or negative pressures shall be evaluated at 2.5 times maximum external pressure expected during service life.		

Launch pad and storages are provided with lightning protection system. Lightning protection system at launch pad consists of 4 numbers of self-supporting steel latticed towers of height 120 m. The towers are at four corners of sides 90m x 108m. Each tower supports 10m tall lightning mast at the top along with the conductor network, inter connecting all the towers at the top and the ground earth system.

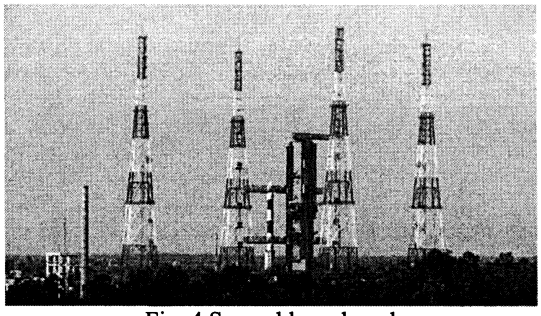

Fig. 4 Second launch pad

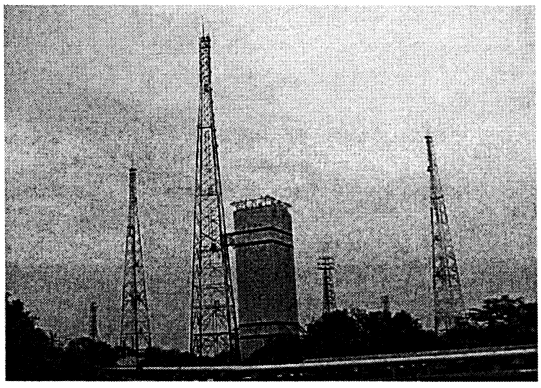

Fig. 5 First launch pad

4.3.1. Lightning and thunderstorm warning

Based on the electric field data, Meteorological Department issues lightning warning alarm in three levels as given below,

Level 1: Pre alarm – (500 V/m – 1000 V/m)
- Alert the personnel for safing action of launch vehicle

Level 2: Alarm – (1001 V/m – 3000 V/m)
- Active thunderstorm cell detected within 20-30 km distance
- New operations not permitted

Level 3: Lightning hazard on site – (> 3000 V/m)
- Active thunderstorm within 5km from launch site

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- Terminate all operations safely and vacate the launch pad

4.3.2. Surge Protection Devices

Zener diode based system or gas discharge tube based surge protection system is incorporated in the launch vehicle-ground systems interface cables at either end as per the signal requirement.

5. FLIGHT SAFETY MANAGEMENT

5.1 Launch commit criteria

The Weather Launch Commit Criteria is well formulated considering the tropical weather, which consists of tropical cyclones, monsoon seasons, thunderstorms and strong tropical winds. In order to support the launch operations, a meteorological facility has been established. This consists of a 100m tall meteorological tower for wind measurement at 9 different levels and continuous recording, surface observatory, Doppler weather radar, real time satellite imagery acquisition system from Indian meteorological satellites, electric field measurement systems and weather balloon ascent facility.

5.2 Flight safety

The objective of flight safety is to protect life and property from malfunctioning rockets. The hazards of the rocket launch are due to impact of rocket stages normally jettisoned during the flight or impacting vehicle fragments resulting from a malfunctioning vehicle. It is always risky to allow a vehicle, which is erratic, to continue it's flight. The malfunction, which is affecting the rocket, may also affect the destruct system, or subsequent violent manoeuvres may render the destruct system inoperative. At the same time, it is a cardinal principle that rockets should not be destroyed solely because they are deviating. If they are deviating, they are destroyed only if they violate the destruct criteria or if in the Range Safety Officer's (RSO) judgement further flight is likely to result in undue hazards.
Flight safety interaction starts from the stage of mission definition and choice of onboard systems and configuration. This should ensure adequate provision of tracking aids, instrumentation to monitor vehicle system performance and incorporation of fail-safe thrust termination / destruct system compatible with the ground telecommand facility.

5.3 Real time data processing for flight monitoring

The radars provide the tracking data required for the computation of the rocket's present position and the instantaneous impact point. SDSC SHAR has three C-band radars and one number of S-band radar. Onboard telemetry system provides the performance of the rocket systems. Two telemetry stations located at SDSC SHAR, three down range stations for GTO missions and two down range stations for SSO missions support the launches. Data from all these sources are received, validated for quality, and processed in real time and suitably displayed. The elements of the real time network used for processing tracking data consist of multiple tracking sources, fail-safe computer network and array of displays for decision making and redundant telecommand systems for issuing mission abort command. The flight safety data display system has many innovative features.

6. SAFETY IN THE LAUNCH VEHICLE DESIGN

6.1 Trajectory design with the day of the launch wind

The mission trajectory is designed, validated and loaded on the launch vehicle's onboard computers on the launch day just few hours prior to the launch window. The main input is the launch day wind data. This is mainly to reduce the aerodynamic loads, minimise the control system fuel requirement and increase the launch probability.

6.2 Flight safety instrumentation and flight termination system

All the launch vehicles are provided with dual redundant radar transponders, two chains of vehicle telemetry and redundant flight termination systems.

6.3 Orbit insertion stage passivation

Passivation of the PS4 stage is successfully implemented in the stage design to avoid any explosions after its useful purpose is completed. Considering the simplicity and safety of the separated spacecraft, venting the pressurant gas from the propellant tank and gas bottles along with the propellant vapours in the tanks through an additional branching in the pressurant lines of each tank using separate pyro valves is selected. After injecting the satellite in the required orbit, final stage of launch vehicle will be reoriented with respect to the orbital plane. After ensuring this, left out pressurised gas in gas bottles and unused liquid propellants will be commanded to flush out from the system.

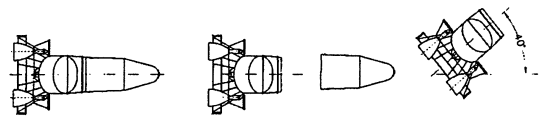

Fig. 6 Sequence of Passivation

6.4 Emergency engine shut off system

In the case of cryogenic upper stage failure to ignite or develop low thrust, the launch vehicle control system

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issues "Emergency shut down" command. Emergency shut down sequence executes the operations such as shutting down the engine, separation of the spacecraft and execution of the venting systems.

7. ON-SITE EMERGENCY PLAN

The exigencies that can arise can be classified into the following categories.

- Fire at launch pedestal after take-off
- Fire inside launch complex after take-off
- Spillage of propellants inside launch complex without fire
- Vehicle debris falling outside the launch complex within the protected zone with consequent fire hazard, including forest fire and propellant spillage
- Vehicle stage or debris falling outside the protected zone with or without fires.

In order to take necessary actions during such exigencies, an on-site disaster management plan has been made for execution by the emergency teams. The details of location of various teams, logistic support requirement, emergency and rescue action plan are well thought off and documented. Training, mock up drills and rehearsals are important for quick action.

8. CONCLUSION

All the rocket launch operations are highly hazardous and are well understood by all concerned. Safety is given prime importance in the facility lay out and design and in the process and operational sequence. On many occasions, the constraints imposed by flight safety policy have restricted the satellite launch missions resulting in non-optimal utilization of the launch vehicle capabilities in terms of payload mass. Thus safety plays an important role in the space research activities of ISRO.

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